Barrier Bucket Studies in the Fermilab Recycler Ring

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High Intensity High Brightness Hadron Beams

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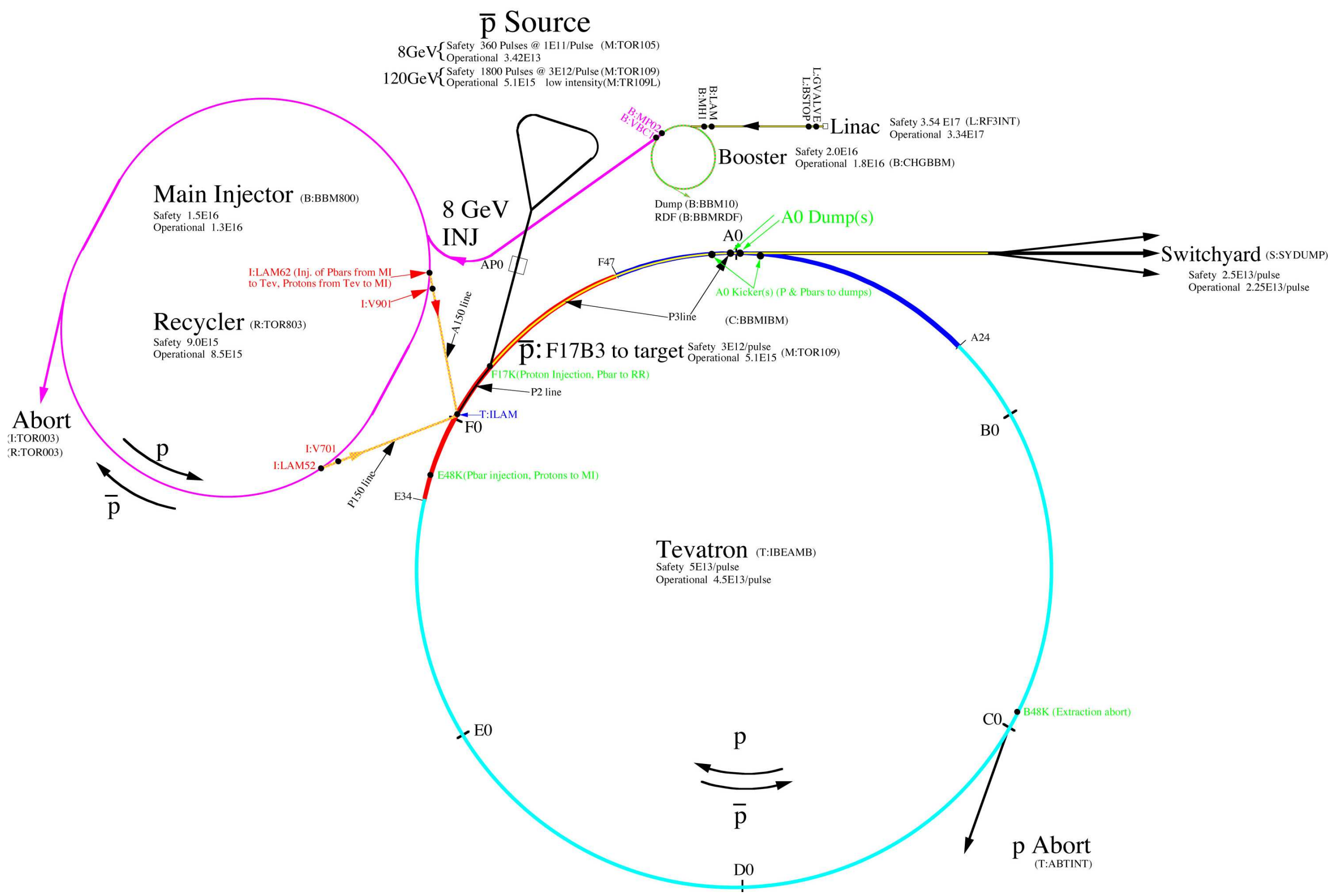
Outline

- Fermilab Recycler Ring (a pbar storage Ring) and its role in Collider Run II
- Barrier Buckets in RR
  - Selection of Wave forms for RR barrier buckets
  - Beam dynamics simulations and RF manipulations in RR
- Beam stacking and unstacking using barrier buckets in RR
- Conclusions and plans

Fermilab Site



Recycler Ring in MI Tunnel

RR Machine Parameters

Table 1.1: Recycler ring parameter list.

Circumference	3319.400	m
Momentum	8.889	GeV/c
Number of Antiprotons	2.5×10^{12}	
Maximum Beta Function	55	m
Maximum Dispersion Function	2.0	m
Horizontal Phase Advance per Cell	86.8	degrees
Vertical Phase Advance per Cell	79.3	degrees
Nominal Horizontal Tune	25.425	
Nominal Vertical Tune	24.415	
Nominal Horizontal Chromaticity	-2	
Nominal Vertical Chromaticity	-2	
Transition Gamma	20.7	
Transverse Admittance	40	π mmmr
Fractional Momentum Aperture	1%	
Superperiodicity	2	
Number of Straight Sections	8	
Number of Standard Cells in Straight Sections	18	
Number of Standard Cells in Arcs	54	
Number of Dispersion Suppression Cells	32	
Length of Standard Cells	34.576	m
Length of Dispersion Suppression Cells	25.933	m
Number of Gradient Magnets	108/108/128	
Magnetic Length of Gradient Magnets	4.267/4.267/2.845	m
Bend Field of Gradient Magnets	1.45/1.45/1.45	kG
Quadrupole Field of Gradient Magnets	3.6/-3.6/7.1	kG/m
Sextupole Field of Gradient Magnets	3.3/-5.9/0	kG/m^2
Number of Lattice Quadrupoles	72	
Magnetic Length of Quadrupoles	0.5	m
Strength of Quadrupoles	30	kG/m

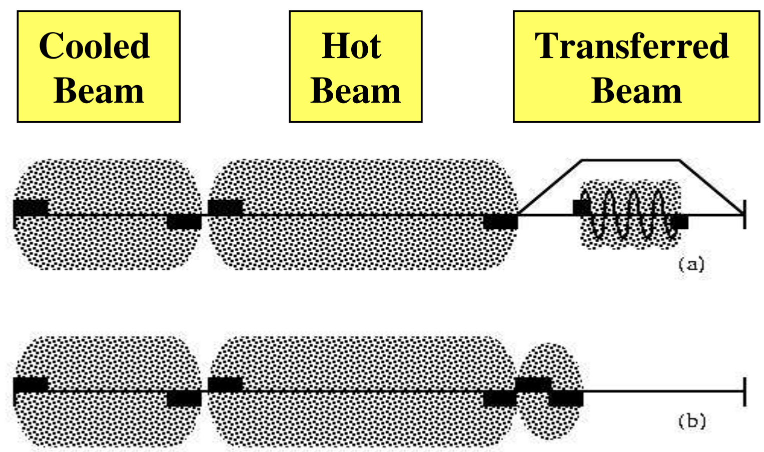
Run II parameters with RR

			With RR		
RUN	Ib (1993-95) (6x6)	Run IIa (36x36)	Run IIa (140x105)	Run IIb (140x105)	
Protons/bunch	2.3×10^{11}	2.7×10^{11}	2.7×10^{11}	2.7×10^{11}	
Antiprotons/bunch*	5.5×10^{10}	3.0×10^{10}	4.0×10^{10}	1.0×10^{11}	
Total Antiprotons	3.3×10^{11}	1.1×10^{12}	4.2×10^{12} **0.48E13**	1.1×10^{13}	**1.25E13**
Pbar Production Rate	6.0×10^{10}	1.0×10^{11}	2.1×10^{11}	5.2×10^{11}	hr^{-1}
Proton emittance	23π	20π	20π	20π	mm-mrad
Antiproton emittance	13π	15π	15π	15π	mm-mrad
β^*	35	35	35	35	cm
Energy	900	1000	1000	1000	GeV
Antiproton Bunches	6	36	103	103	
Bunch length (rms)	0.60	0.37	0.37	0.37	m
Crossing Angle	0	0	136	136	μrad
Typical Luminosity	0.16×10^{31}	0.86×10^{32}	2.1×10^{32}	5.2×10^{32}	$cm^{-2}sec^{-1}$
Integrated Luminosity†	3.2	17.3	42	105	pb^{-1}/week
Bunch Spacing	~3500	396	132	132	nsec
Interactions/crossing	2.5	2.3	1.9	4.8	

Required Initial Cooled Beam

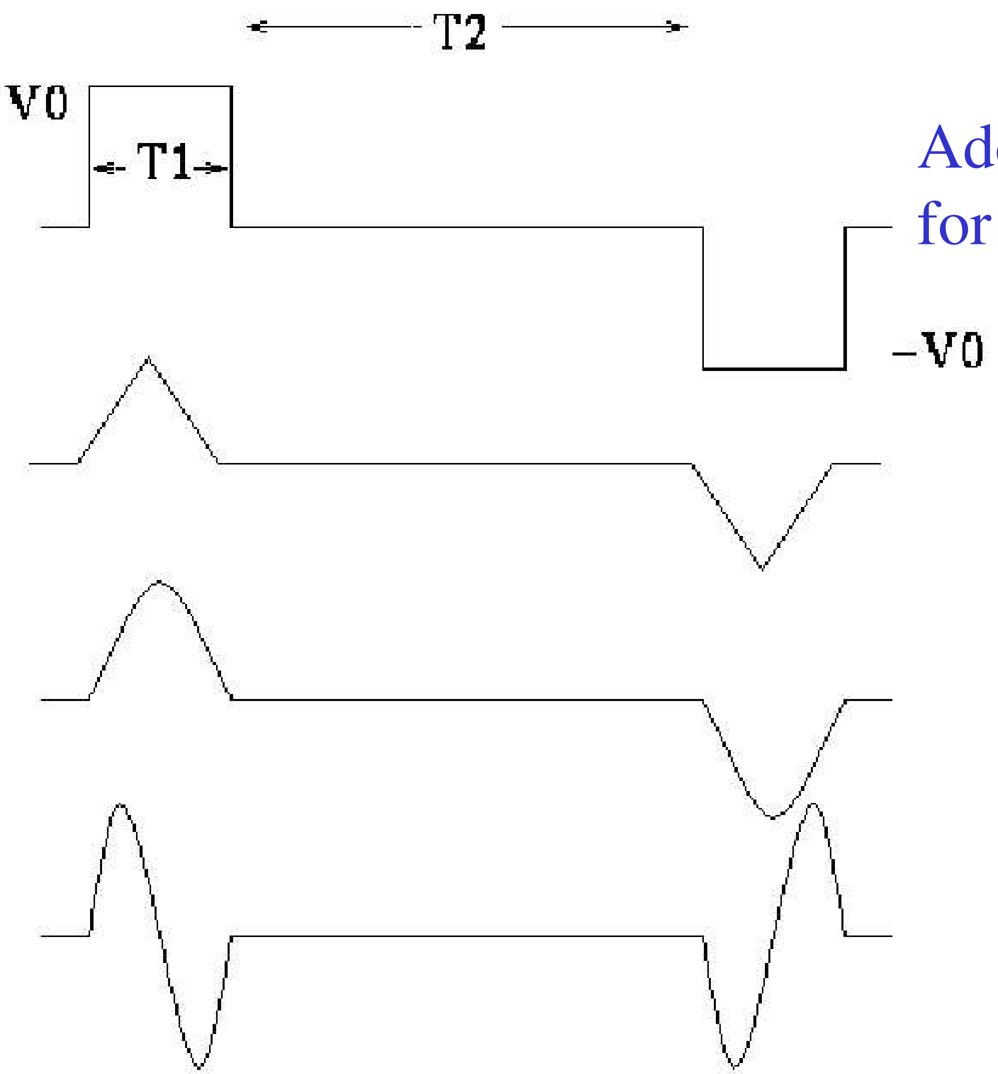
Why do we have to use barrier buckets in RR?

- RR is an 8 GeV pbar storage ring. At any given time, the RR requires to have up to three different regions



  - Cooled beam ~54 eVs,
  - Hot beam ~108 eVs
  - Transferred beam ~10 –16 eVs
- Each one of them serve specific functions.These specifications demand use of barrier buckets.

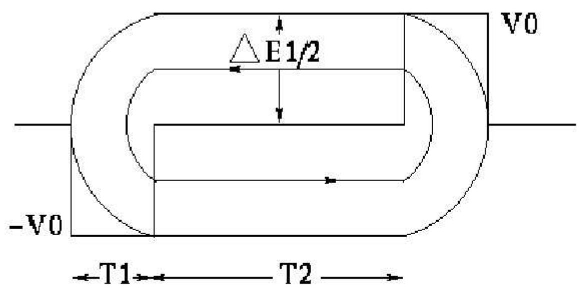
Choice of RR Barrier Buckets



Adopted for RR

The RR runs below transition energy. Therefore the wave shapes have to flip.

Properties of Barrier Bucket



Bucket area :

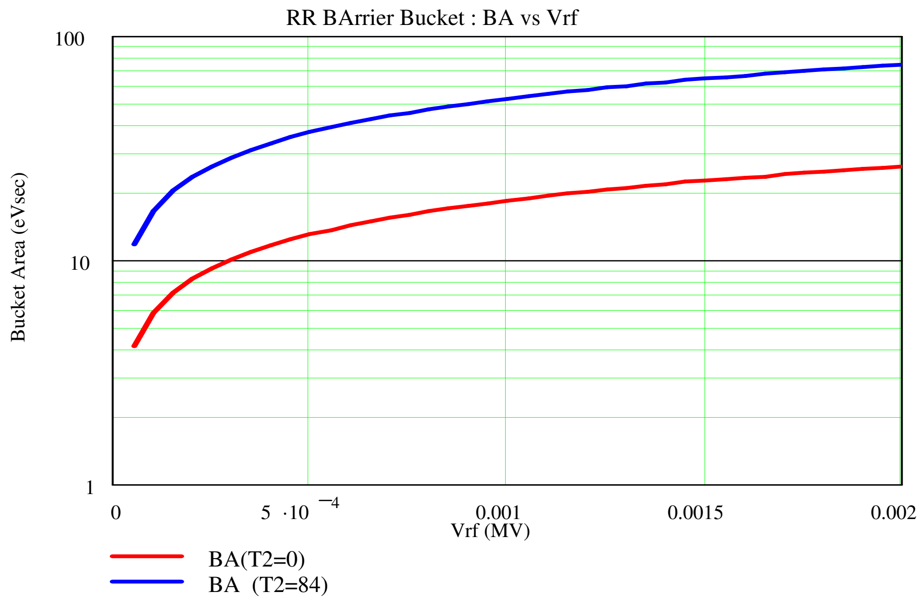
$$\mathcal{A} = 2T_2\hat{\Delta E} + \frac{8\pi|\eta|}{3\omega_0\beta^2 E_0 eV_0}(\hat{\Delta E})^3.$$

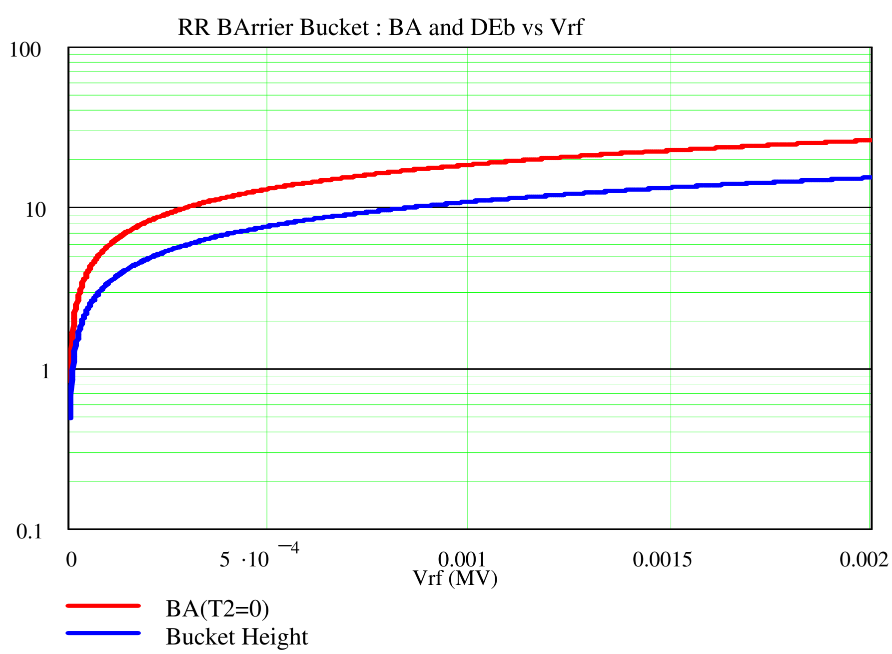
Bucket half height :

$$\Delta E_b = \left(\frac{eV_0 T_1}{T_0}\frac{2\beta^2 E_0}{|\eta|}\right)^{1/2}$$

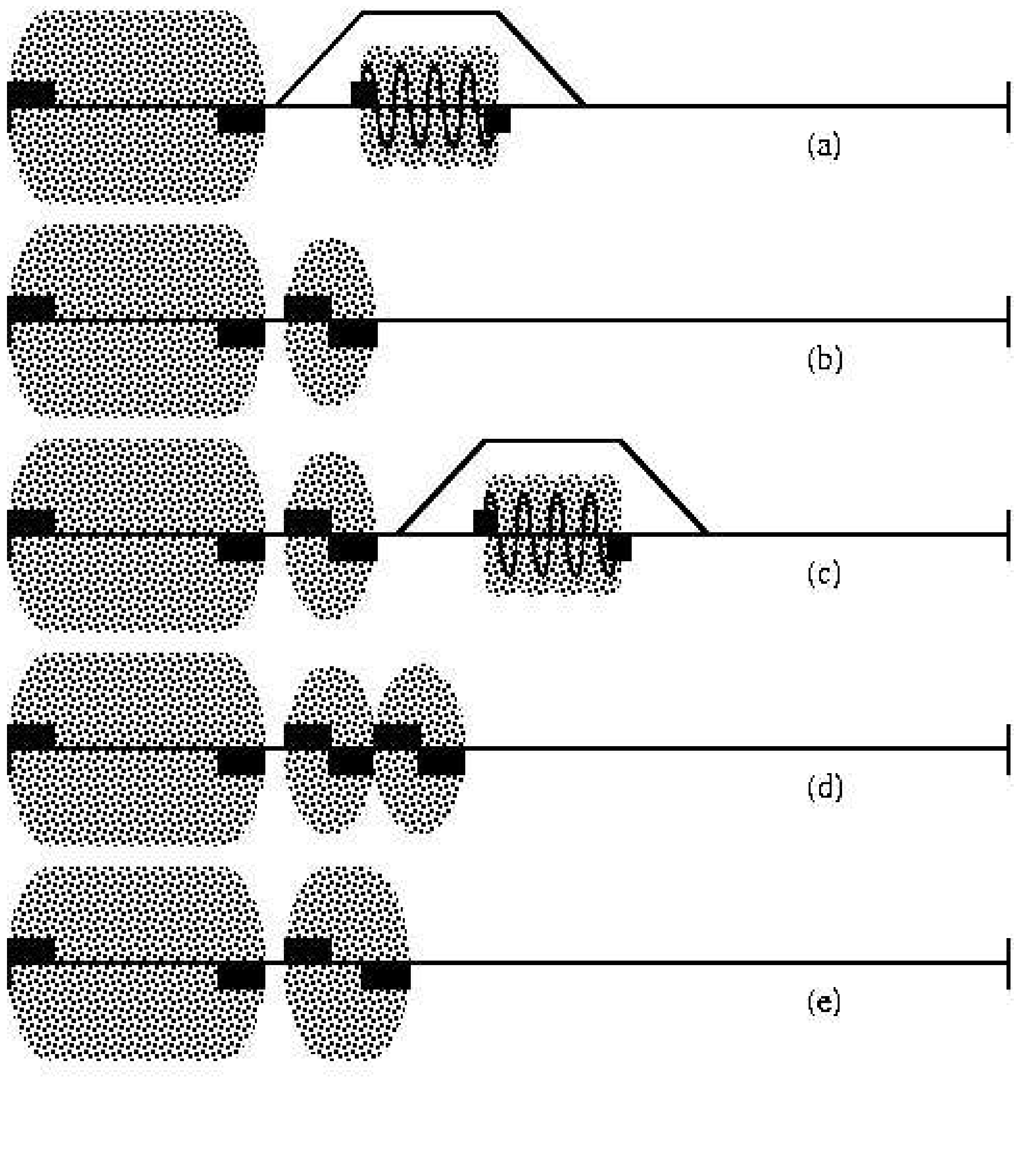
- η is phase slip factor,
- E_o is synchronous energy,
- $\omega_o = 2\pi\, f_{rev}$ with f_{rev}= beam circulation frequency.

Barrier Bucket





RF Manipulations in RR using Barrier Buckets for Stacking



Computer Simulation of Beam Stacking in RR

(with Jim Maclachlan)